Long duration, high altitude, super pressure balloons; Design considerations and advances in analytical support

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Abstract

Long duration, high altitude pressurized balloons, often colloquially referred to as 'pumpkin' balloons, have uses in the fields of scientific or meteorological research, telecommunications and recreation. Whilst the overall structural system of these balloons is easily described, subtleties of performance as a consequence of the visco-elastic nature of the balloon envelope, the large temperature delta from manufacture to deployment, the interface between the film and tendon and susceptibility to instability, make the detailed design of these balloons far from straightforward.

Tensys have been involved in the numerical form finding and load analysis of architectural stressed membrane structures for almost thirty years using their in-house Finite Element (FE) software suite, inTENS [1-3]. Tensys Dynamics Ltd (TDL) was formed in 2004 to provide a similar consultancy service for the aerospace industry. TDL has been providing analytical support to various 'pumpkin' balloon programs for 15 years.

The paper will introduce this form of balloon in terms of overall geometry, uses and the basic structural system. Balloon construction and the early problems of geometric and deployment instability will be briefly reviewed [4-10]. A typical design process [11-12] will be described from the context of the analytical support. Both the capabilities of inTENS and the fidelity of the FE models have improved over time to keep pace with balloon design developments and program requirements [13-15]. Extensive smaller FE models have also been developed and analysed to examine particular local phenomena witnessed in flight or to support investigations into potential failure mechanisms.

The balloon skin is formed from thin polyethylene film, cut into a series of identical strips called 'gores', spanning between a braided PBO tendon skeleton. The thorough characterisation of these two component materials is critical to accurate FE modelling. The visco-elastic material model used to represent the film continues to evolve from the original Schapery Rand implementation [16-17] to the current Caltech large strain time dependent model [18-22]. Implementation of the Caltech material model into the inTENS code facilitates time stepping analysis runs.

Balloon programs are supported by a large range of physical tests. These tests vary from small scale uniaxial and biaxial film tests associated with material characterization, tests on local components of a balloon, model balloons up to testing of full scale articles. These tests are typically undertaken at both room and cold temperatures and provide a good opportunity to validate FE analyses.

A major consideration in the design of a pumpkin balloon is the balance of desired stress in the two film directions (meridional and transverse direction). This discussion introduces topics such as global foreshortening (the relative gore / tendon length) and the nature of the interface between the film edge and tendon. The factors affecting the performance of, and developments in the modelling of this interface will be studied.

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